Effectiveness of Domain Ontologies to Facilitate Shared Understanding and Cross-Understanding

Research-in-Progress

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Abstract

Shared cognition constructs such as shared understanding and cross-understanding are important factors in team performance. Although research has focused on understanding the effects of these constructs, little emphasis has been placed on improving their development. In Information Systems and related fields shared understanding of a domain is said to be facilitated by the use of a domain ontology, however there is a lack of empirical evidence to support this claim. Accordingly, in this research-in-progress paper, we report our efforts to develop a deep understanding of the benefits of domain ontology use at the group level. Specifically, we propose a model that theorizes the relationships between domain ontology use and the development of shared understanding and cross-understanding of domains. Additionally, we provide details of operationalization and empirical validation of our model, and the current state of this research.

Keywords: Conceptual Modeling, Domain Ontology, Shared Understanding, Cross-Understanding, Communication Effectiveness

Introduction

Practitioners and researchers consider *shared understanding* (SU) and *cross-understanding* (CU) as important constructs for successful performance of teams in group tasks (Bittner and Leimeister 2014; Huber and Lewis 2010). These two constructs are determined at the group level by considering the participation of all group members as contributors (Huber and Lewis 2010). The first construct, SU, refers to the extent of common comprehension of a topic among team members (Ko et al. 2005). Whereas CU refers to the extent to which team members accurately understand the mental model of another team member regarding a specific topic (Huber and Lewis 2010). Although research has extensively explored the impact of these group-level constructs, there is a lack of studies exploring how to facilitate or to improve the development of SU or CU (Bittner and Leimeister 2014; Huber and Lewis 2010).

In Information Systems (IS) and related fields, one of the oft-cited benefits of the use of domain ontologies (DO) to support human tasks is the facilitation of SU of the domain represented in these ontologies (Roa et al. 2014). DO can be explained as "a description of concepts and their interrelationships in a particular domain" (Bera et al. 2011, p. 884). However, despite the popularity and high number of existing DO, there is a lack of empirical evidence with regards to their facilitation of SU (Roa et al. 2014). Moreover, prior research also indicates that current ontology development methodologies lack recommendations for evaluating effectiveness of ontologies for the purpose they were developed such as, for example, facilitation of SU (Roa et al. 2014). It is therefore important to explore whether the claimed effectiveness of DO in regards to facilitating SU is evident in practice. In addition, we are motivated to extend the investigation of SU to also include that of CU given its importance in teams and the paucity of research on how to facilitate development of CU.

Accordingly, to address this gap in the body of knowledge in IS, the aim of this research is to understand theoretically and empirically the effectiveness of DO to facilitate SU and CU of domains. Specifically, our main research question in this study is *"Are DO effective in facilitating SU and CU of domains?"* Our subsequent question is *"What is the impact of ontology representation quality on the effectiveness of DO to facilitate SU and CU of domains?"* We are specifically interested in *representation quality* because prior research shows that a variation in *representation quality* can considerably affect the interpretation of ontologies and the individual level construct of domain understanding (Bera et al. 2011; Mayer 2009).

To investigate our research questions, we developed a theoretical model as a basis for the empirical testing of impact of DO use on SU and CU. The theoretical model is based on a usage process of DO to facilitate SU and CU. This process considers theories of conceptual modeling (Burton-Jones et al. 2009; Gemino 2004) to describe the use of ontologies at the individual level, and theories of shared cognition to extend the use of ontologies at the group level (Cannon-Bowers and Salas 2001; Resnick 1991; Salas et al. 2008). Accordingly, the theoretical model and its operationalization theorize the influence that effective DO have in SU and CU. Finally, through a laboratory experiment, we propose to evaluate our operationalized model to explore the effectiveness of DO in facilitating SU and CU. To do this, our study focuses on one instance of a DO – the Compliance Management Ontology (CoMOn) (Syed Abdullah et al. 2012). Compliance management has been an important topic discussed within academia and industry for three main reasons: high-compliance management cost (Protiviti 2012), drastic consequences of failing to comply (Australasian Compliance Institute 2013b), and a weak and conflicting understanding of compliance management concepts in organizations (Australasian Compliance Institute 2013a; Open Compliance & Ethics Group 2012). Thus, compliance management is a suitable setting in which to study the effectiveness of DO in facilitation of SU and CU.

This paper reports the current progress towards constructing our theoretical model and its empirical validation. In the next sections, we present a review of background concepts and related work, the development of our theoretical model and its operationalization, the progress towards its empirical validation, and finally, we conclude with a discussion of limitations and future contributions.

Background Concepts and Related Work

To clarify relevant concepts and understand prior work in this field we considered two independent literature review rounds with a systematic approach that included a backward and forward search (Tamm

et al. 2011). First, a review of shared cognition literature provided a basis for the development of a comprehensive view of the shared cognition constructs used in this study. In this review, we used the *Scopus* database to search for highly cited publications that included the terms 'shared understanding', 'shared cognition', 'shared mental models', 'common understanding', 'common mental models'. Through a backward and forward search of citations we then identified other relevant publications that allowed us to clarify the terms SU and CU. Second, a review of ontology literature contributed to defining domain ontology and identifying various notions of DO effectiveness – for more details refer to Roa et al. (2014). In the following, we present the main results of these review processes.

Shared Cognition Constructs

Shared cognition constructs such as SU and CU have been extensively studied in psychology and management research (Cannon-Bowers and Salas 2001; Huber and Lewis 2010). However, various studies consider diverse definitions for these constructs (Bittner and Leimeister 2014). In this study, we define SU as a synonym of shared mental model (Mathieu et al. 2000), that is, the extent of common comprehension of a topic among team members (Ko et al. 2005). For CU we adopt Huber and Lewis (2010, p. 7) definition: "the extent to which team members have an accurate understanding of another's mental model."

Because these constructs relate to *shared* cognition, they are determined at the group level i.e. they have as contributors the members of a team or group (Huber and Lewis 2010). SU has as contributors the mental model of each team member and is measured through the extent of similarity of those mental models. CU has as contributors the accuracy of each team member's understanding of another team member's mental model (Huber and Lewis 2010), and is measured through the extent of accuracy of understanding of another's mental model.

Domain Ontologies

The term 'Ontology' defines the branch of philosophy that studies the nature and structure of reality (Smith 2008; Wand and Weber 1993). However, this term is also used in other research fields, such as science and engineering for example, to express a range of diverse meanings including theories, informal conceptual systems, formal semantic accounts, specifications of conceptualizations, vocabularies of logical theories, among others (Giaretta and Guarino 1995; Weber 2002). This situation has made it difficult to achieve a consensus about what ontologies are. Indeed, a lack of consensus among different fields still remains despite some efforts being undertaken to establish common ontology definitions among different fields – e.g. Almeida (2013), Fonseca (2007), Giaretta and Guarino (1995), Hepp (2008), Kishore and Sharman (2004), Weber (2002).

In this study, we define an ontology as a specification of a shared conceptualization of reality, which has varying levels of generality and representation formality. In this definition, 'conceptualization' refers to an abstract model of reality through concepts and relations relevant to that reality (Studer et al. 1998); 'shared' refers to an ontology capturing consensual knowledge of reality by a group of experts in that reality (Studer et al. 1998); 'levels of generality' refers to the notion that ontologies can be very general (the whole reality) to very specific (a domain in particular); and 'formality' refers to how an ontology can be specified through formal means such as the Web Ontology Language (OWL) (Bera et al. 2011), to informal means such as a graphical representation of concepts and their relationships (Grimm et al. 2011). Consequently, we refer to a domain ontology as the specification of a shared conceptualization of a domain, which can be established through formal or informal means.

Effectiveness of Ontologies

There are two general uses of ontologies that can be identified in practice: computer centric and human centric (Roa et al. 2014). One use is related to the *support of computer systems,* such as information retrieval (Neches et al. 1991), interoperability of computer systems (Berners-Lee et al. 2001), knowledge representation (Horrocks and Patel-Schneider 2011), systems based on ontologies (Lutz and Klien 2006), among others. The other is related to the *support of human tasks*, such as analysis of conceptual modeling grammars (Recker et al. 2009), facilitation of conceptual modeling (Wand et al. 1999),

development of domain understanding (Bera et al. 2011), ontology construction (Suárez-Figueroa 2012), and facilitation of SU (Innab et al. 2012; Lin et al. 2004; Uschold et al. 1998).

The effectiveness of these two types of ontology use differs considerably. The effectiveness of ontology for the *support of computer systems* can be validated through prototypes and their functionality (Roa et al. 2014). For the *support of human tasks* empirical evidence is necessary to explore the effectiveness of ontologies (Roa et al. 2014). Our literature review indicates that ontologies are effective in supporting most of the human tasks that we listed above (Roa et al. 2014). Some examples of empirical evidence can be found in studies such as Gašević et al. (2009), Recker et al. (2011), Sugumaran and Storey (2006) to name a few. However, we could not find studies exploring whether ontologies facilitate SU, despite a high number of ontologies having been developed for this specific purpose (Roa et al. 2014).

Based on this lack of evidence, we analyzed highly cited ontology development methodologies, specifically focusing on whether they include guidance for ontology evaluation. We considered two types of evaluations, namely, an evaluation at the conclusion of ontology development but before the ontology is put into use (*ontology quality*) and an evaluation after the ontology is put into use (*ontology effectiveness*). Our review indicates that most ontology development methodologies lack steps or guidelines for evaluation of ontology effectiveness (See Table 1).

Table 1. Types of Evaluation in Ontology Development Methodologies (Adapted from Roa et al. 2014)

Methodology Name	Ontology Quality	Ontology Effectiveness
Cyc (Guha and Lenat 1990)		
N/A- (Gruber 1995)		
Based in Enterprise Ontology (Uschold and King 1995)	x	
Based in TOVE (Grüninger and Fox 1995)	x	
KACTUS (Gómez-Pérez et al. 2004)		
METHONTOLOGY (Fernández-López et al. 1997)	x	
Based in SENSUS (Swartout et al. 1997)		
Ontology Development 101 (Noy and McGuinness 2001)		
Based in On-To-Knowledge (Staab et al. 2001)	x	
DILIGENT (Tempich et al. 2005)	x	
HCOME (Kotis and Vouros 2006)	x	
OntoClean (Guarino and Welty 2009)	x	
UPON (De Nicola et al. 2009)	x	
DOGMA (Jarrar and Meersman 2009)		
Based on DO4MG (Delir Haghighi et al. 2013)	x	x
NeOn (Suárez-Figueroa 2012)	x	x
Based on CoMOn (Syed Abdullah et al. 2013)	x	x

Our review of literature also indicates that most ontologies developed with the specific purpose of facilitating SU are represented graphically. Indeed, empirical evidence shows that users prefer graphical representations when solving tasks, leading to superior performance in the tasks compared with other kind of representations (Figl and Recker 2014; Mayer 2009). Moreover, whilst graphical representation is predominant, the quality of this representation can vary considerably and a small change in the graphical representation can affect the interpretation of the ontology (Bera et al. 2011; Mayer 2009).

In summary, our review shows that some domain ontologies – especially graphical domain ontologies – have been developed to facilitate the development of understanding at the group level. However, our review also shows that there is a lack of empirical evidence that provides further insights of ontology effectiveness in facilitating the development of SU or CU. Despite research indicating that unambiguous visualizations, e.g. such as statistical graphics, can contribute to the development of shared constructs (Swaab et al. 2002), ontologies differ considerably in the quality of visualization and more evidence is required to understand ontology effectiveness in such settings. This gap in the body of knowledge has

been noticed by IS academics. For instance, Burton-Jones and Weber (2014, p. 18) indicate that the development of SU among users of graphical representations of a domain (conceptual models) has not been studied before, and discuss that research focused on the understandability of these graphical representations has so far focused on the individual level (Saghafi and Wand 2014) rather than the group level at which SU is defined.

Theoretical Development and Operationalization

To address the lack of empirical evidence for the effectiveness of ontologies in facilitating understanding at the group level, we have developed a theoretical model of ontology effectiveness for such settings based in our literature review. Our model is based on an ontology-usage process to facilitate SU and CU. The model has three phases, as shown in Figure 1.

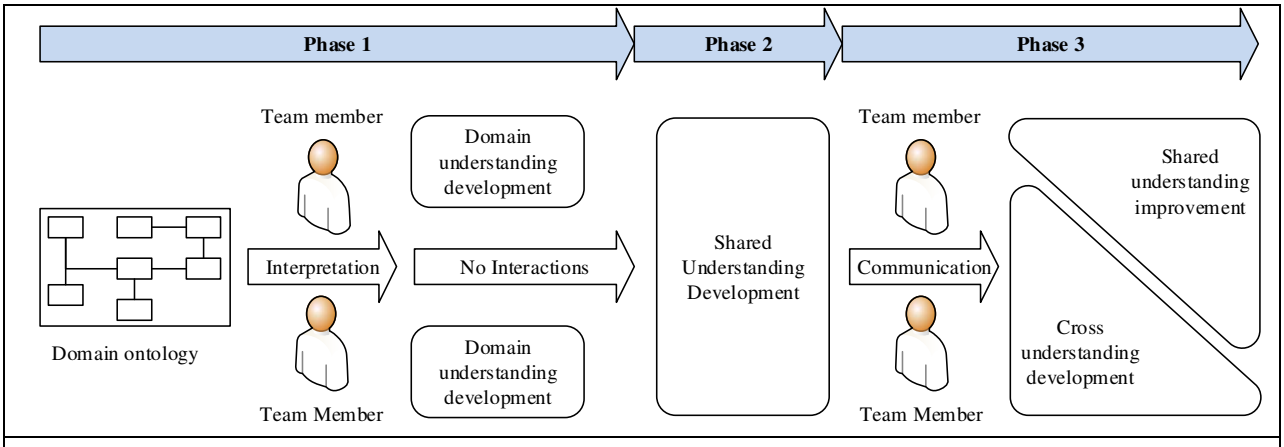

Figure 1. Usage Process of Domain Ontologies to Facilitate SU and CU

In the first phase, each team member interprets the ontology to create an individual mental model of the domain, that is, domain understanding. This interpretation process is defined in traditional conceptual modeling research, whereby users interpret a representation of a domain to develop an understanding of that domain (Burton-Jones et al. 2009; Gemino 2004). For instance, users interpreting a visual ontology are able to perform knowledge identification tasks, which is a particular result of domain understanding (Bera et al. 2011).

In the second phase, a shared mental model of the domain among team members can be achieved before they interact with each other. Psychology research establishes that some shared cognition constructs, such as SU, can be established through providing external sources of information without interaction between team members (Resnick 1991). Similarly, research defines and measures those shared constructs as the variation among the individual cognition constructs between team members (Johnson and O'Connor 2008; Salas et al. 2008; Tan and Hunter 2002). Accordingly, when each member interprets the ontology to create a mental model of the domain it is possible to establish how diverse those individual mental models are by comparing them with each other. The extent of overlap of those mental models is the SU of a domain.

Finally, to improve SU and achieve CU team members must communicate effectively with each other, which occurs in phase three. However, communication by itself will not result in achieving these goals: personal thoughts and points of view about the domain have to be exchanged for the communication to be effective (Mathieu et al. 2000; Stein et al. 2011). To ensure *communication effectiveness*, we theorize that the use of ontologies as tools to clarify a phenomenon in the domain can lead to a more effective exchange of appropriate information about the said domain. Our assumptions are based on the definition of the *conveyance process* of the *Theory of Media Synchronicity* (Dennis et al. 2008). This process indicates that new and relevant information has to be exchanged between team members to achieve success in team communication.

Accordingly, when team members achieve effective communication, they can discuss specific differences in their mental models and try to achieve an agreement about the domain. If an agreement is achieved on discrepancies about the domain then SU is improved (Kayworth and Leidner 2002). Additionally, regardless of whether SU is improved, team members develop a better understanding of the other's mental models of the domain (Mathieu et al. 2000; Stein et al. 2011), leading to the creation of CU.

However, many other factors can also affect the effectiveness of ontology. Because domain ontologies are used as tools in this process, any factor affecting the interpretation of the ontology will affect its effectiveness. For example, representation formality, *representation quality*, visualization approaches, ontology quality, user knowledge, and user experience, among others (Burton-Jones et al. 2009; Gemino 2004). In our study, we are specifically motivated to explore how *representation quality* impacts upon graphical ontologies and their facilitation of SU and CU. We chose this factor because graphical representation varies considerably among ontologies and small variations of representation can affect the user's interpretation (Burton-Jones et al. 2009; Gemino 2004). To measure the effect of *representation quality* we propose a model of ontology effectiveness to facilitate SU and CU. The model proposes that domain ontologies facilitate SU and CU and increase *communication effectiveness*, as summarized in Figure 2.

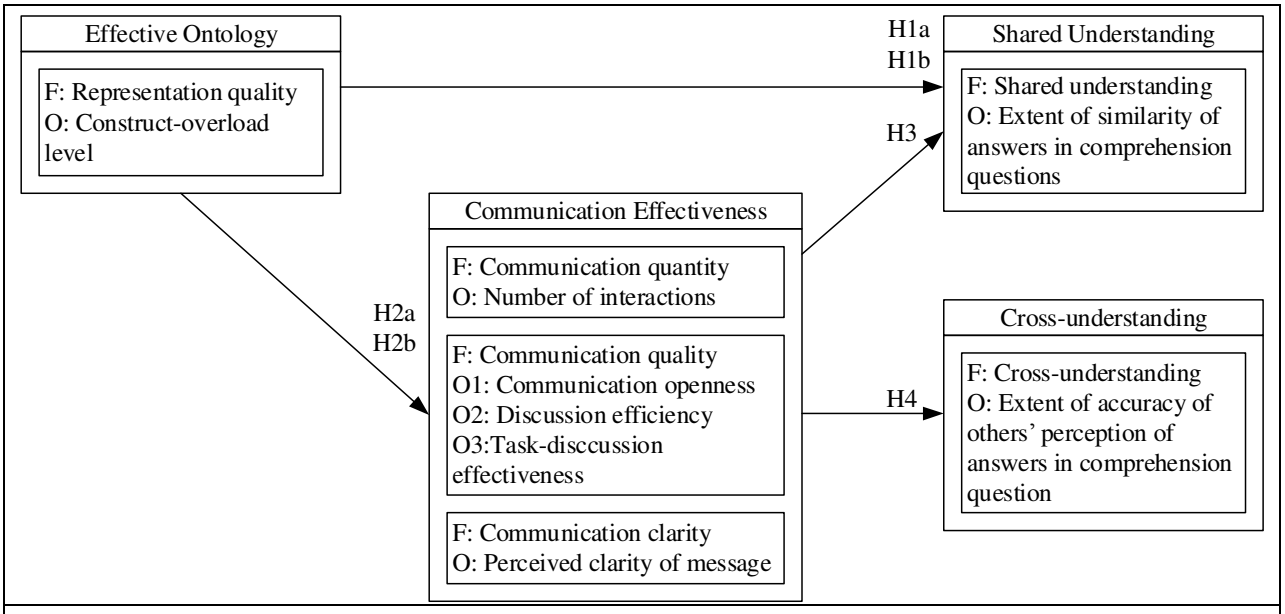

Figure 2. Model of Ontology Effectiveness to Facilitate SU and CU
(F: Theoretical Factor; O: Operationalization of Factor)

The first set of hypotheses relates to the achievement of SU. Studies in conceptual modeling research show that the quality of conceptual representations can positively affect the understanding of users (Bera et al. 2011; Burton-Jones and Meso 2008). Analogously, if team members understand the domain better, it is more likely that each team member understands similar facts about the domain. Therefore we propose the following hypotheses:

- H1a. Team members who use a domain ontology develop higher levels of SU than those who do not use a domain ontology.
- H1b. Use of a high-quality ontology representation is associated with higher levels of SU than using a low- quality ontology representation.

We propose to operationalize the *representation quality* of the ontology by using the concept of construct overload. According to the *Theory of Ontological Expressiveness* (Wand and Weber 1993), construct overload occurs when a grammatical construct maps to more than one ontological construct (Burton-Jones and Weber 2014). Thus, by varying construct overload of the ontology we can alter the quality of the ontology representation.

The model also considers three different factors for *communication effectiveness*, namely: quantity, quality, and clarity. The quantity of information exchanged during communication among team members can lead to achieving agreement about the point of discussion (He et al. 2007; Kacmar 2003; Lowry et al. 2009). However, the quantity of information exchanged is not sufficient for a successful communication process (Kayworth and Leidner 2002), the information must also be of high quality in terms of its relatedness with the domain phenomenon in discussion (Kayworth and Leidner 2002). Finally, despite the quantity and the content quality of the exchanged information, if team members do not communicate clearly, the communication will not be effective (Ko et al. 2005). Consequently, we propose the following hypotheses:

- H2a. Team members who use a domain ontology engage in a more effective communication in terms of quantity, quality and clarity than those who do not use a domain ontology.
- H2b. Use of a high-quality ontology representation is associated with better communication quantity, quality, and clarity than using a low-quality ontology representation.

With regards to *communication effectiveness*, we propose to operationalize communication quantity through the frequency of team member interaction (He et al. 2007; Kacmar 2003). We propose to operationalize communication quality through three measures, namely: communication openness, discussion efficiency, and task-discussion effectiveness (Lowry et al. 2009). We propose to operationalize communication clarity through the perception each team member has about the clarity of the messages conveyed during the communication (Kayworth and Leidner 2002).

As per the ontology usage process, during a more effective communication, users can focus on relevant information represented about the domain and are therefore able to better exchange their beliefs and personal knowledge with one another, thus improving SU and leading to the achievement of CU. Contrarily, during a less effective communication, users are distracted and need to bring to bear prior knowledge to interpret the representation, the focus of the discussion may be disrupted and lead to a low exchange of information about the domain between users. Thus, we hypothesize:

- H3. Team members who engage in more effective communication in terms of quantity, quality and clarity have greater SU improvement than those that engage in less effective communication.
- H4. Team members who engage in more effective communication in terms of quality, quantity, and clarity develop greater CU.

As previously discussed, SU is a direct result of the similarity in users' domain understanding. Thus, we establish SU through comparing the individual understandings of team members (Tan and Hunter 2002), and we operationalize SU through establishing the extent of similarity of answers in comprehension questions between team members. CU can be operationalized in two main ways, *viz*. perceptual approach and behavioral manifestation approach (Huber and Lewis 2010). Each approach has some shortcomings. On the one hand, the perceptual approach is easy to execute, but is based on the perception of participants. On the other hand, the behavioral manifestation approach is based on the perception of an external observer and is difficult to implement and quantify in terms of levels of understanding. In our study, we adopt the perceptual measurement approach because it is less subjective to code for analysis. We implement this method by asking each user his/her perception of answers that the other user will give to the comprehension questions. We will then evaluate the extent of accuracy of those perceptions.

Empirical Validation

We chose laboratory experiments because we are interested in providing a higher internal validity to the evaluation of our theoretical model (Cook and Campbell 1979). The experimental setting has the following characteristics. First, we selected two treatment groups (i.e. a higher-quality ontology representation and a lower-quality ontology representation) and a control group (no ontology). As mentioned earlier, we will use the CoMOn ontology (Syed Abdullah et al. 2012) to perform the experiment. This ontology was developed for the specific purpose of providing SU of the *compliance management* domain and was empirically evaluated to establish the quality of the ontology (Syed Abdullah et al. 2012). The ontology will be visualized through graphical representations in the same way as previous studies – e.g. Bera et al. (2011). We proceed in this way because we are more interested in the ontology artifact itself rather than any visualization tool, which is not within the scope of this study. Figure 3 shows an excerpt of a graphical representation of CoMOn.

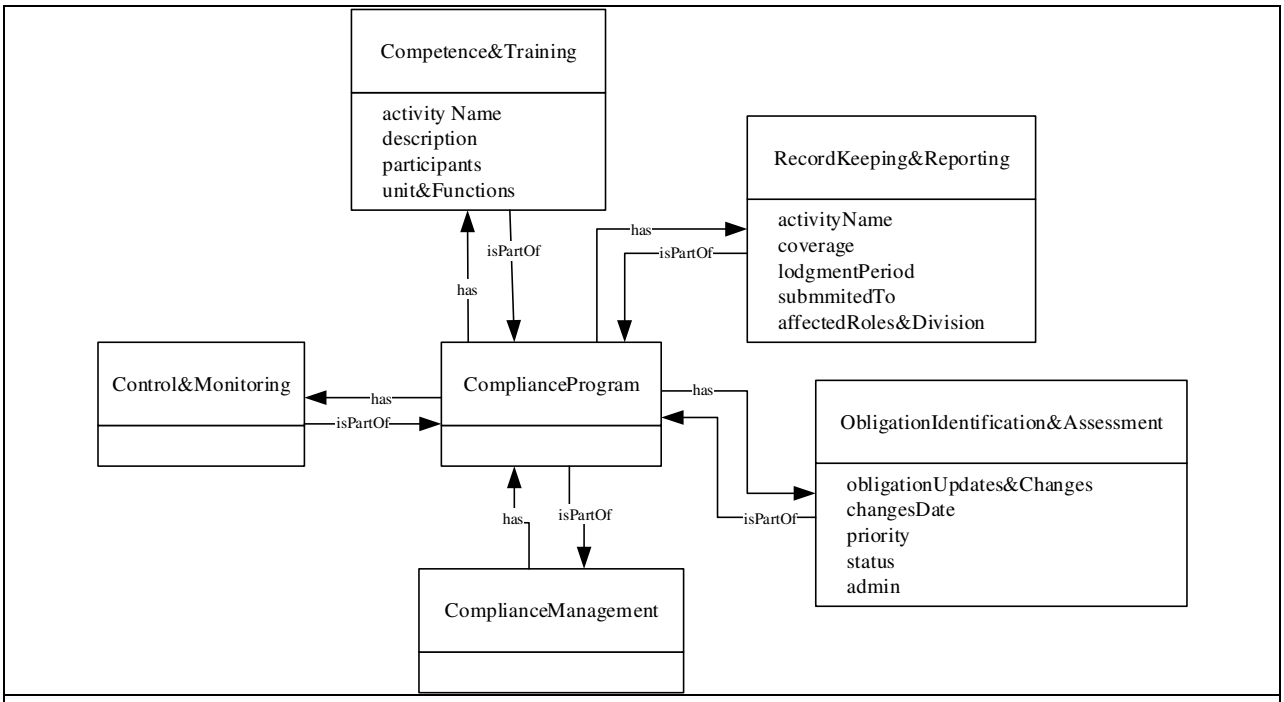

Figure 3. An Excerpt of a Graphical Representation of CoMOn

Initially, the participants will participate in a short tutorial on how to perform the tasks. Following the tutorial, the participants will be briefly questioned on what they gained from the tutorial to check if they understood the task appropriately. The participants will then receive the ontology (or a document including compliance management information in the control group). At this stage, participants will work individually to answer comprehension questions. These results will establish the degree to which SU has been achieved before team members interact (see Figure 1).

Participants will then collaborate with their partner to analyze a compliance management phenomenon. The phenomenon will be related to the initial comprehension questions in such way that the discussion can contribute to better understanding of the domain. The two treatment groups will have the ontology (with different *representation quality*) as a tool to aid their task progression, whilst the control group will only have a document outlining relevant compliance management information. The discussion process will be audio recorded to analyze *communication effectiveness* in terms of quantity, quality, and clarity. Following the paired discussion about the task, participants will each be quizzed again with similar comprehension questions, but with added questions about their perception of the partner's understanding.

For the purpose of this study, participants will have no or a low level of knowledge in compliance management as well as conceptual modeling. We select this group of users because improvement of SU and CU is more important and significant in novice users than expert users (Burton-Jones and Meso 2008). Consequently, participants of our study will be sourced from a pool of students who are taking an IS course at a university. Students in this introductory course have a diversity of student's skills and future professional development, which will be beneficial in two ways. First, it acts to simulate the complexity of a real compliance management organizational setting, and second, this diversity will ensure stronger effects in the theorized factors.

Currently, we are in the pilot stage of these experiments. The pilot experiment has allowed us to verify that significant variation can be distinguished between control and treatment groups and has facilitated the improvement of the experimental materials, and establishing suitable durations for the experiment.

Conclusions, Limitations and Future Contributions

This paper describes our efforts to develop a model that hypothesizes the effect of ontologies on SU and CU, and its empirical validation. Our model theorizes that the *representation quality* of DO influences positively the development of SU and *communication effectiveness* in team groups, and this *communication effectiveness* also influences positively the improvement of SU and the development of CU. Finally, we propose the empirical validation of the model through laboratory experiments and we describe the current stage of this validation.

This study is not without limitations. The primary limitation of this research is that the model does not capture all the variables in the phenomenon. However, we believe that the theoretical model captures the most pronounced variables that influence ontology effectiveness. Other influences are outside of the scope of the study due to the complexity of the phenomenon. For example, our theoretical model only considers one variable, *representation quality*, related to the effectiveness of the ontology. However, additional factors contributing to ontology effectiveness should be explored in future research. Another limitation is that our empirical study is based on an experimental setting. Although an experiment will allow us to control and manipulate variables, the results could differ considerably from a real setting. We also recognize the artificiality of the participants, the experimental tasks, and the quality of the ontology are limitations of our study. Despite these limitations, the study is beneficial in contributing to the advancement of understanding of the effect of ontologies at the group level. We aim to provide the first insights to understand the phenomenon.

At the conclusion of this study, we expect to have contributed on a number of different fronts. First, we expect to contribute to IS research through the theory of ontology effectiveness to facilitate SU and CU. Our findings will allow researchers to improve their understanding of the effect of ontologies, which can lead to improved ontology construction, design and evaluation. Second, we expect to change the current paradigm in conceptual modeling theory from the individual perspective to the group perspective. We note that even though conceptual models, including ontologies, have been used at the group level, this use has not been theorized or evaluated empirically until now. We also expect to contribute from a methodological standpoint through developing methods for measuring CU. Of what we know, we are the first to empirically test CU. Furthermore, from a practical perspective, the study will help organizations understand whether the use of domain ontologies is likely to have a positive impact on organizational communication, interaction, and knowledge transmission. This is predicted to impact on the development of new tools that improve understanding in team settings. Finally, our study will have implications for the compliance management field through the indication of whether the CoMOn ontology can facilitate an improvement of compliance management understanding at the group level. Compliance management difficulties partially stem from diverse stakeholder perspectives (Australasian Compliance Institute 2013b), which through this research may be proven to be able to be successfully bridged with a domain ontology such as CoMOn.

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